Proceedings of the 3rd IASME/WSEAS Int. Conf. on HEAT TRANSFER, THERMAL ENGINEERING AND ENVIRONMENT, Corfu, Greece, August 20-22, 2005 (pp349-353)

Determination of Productivity for Separate Layers in a Geothermal Well based on Well Log Temperature

E. TORHAČ[1], J. KROPE[2], D. GORIČANEC[2]
[1]Nafta-Geoterm d.o.o., Mlinska ulica 5, 9220 Lendava,
[2]Faculty of Chemistry and Chemical Engineeing,
University of Maribor,
Smetanova ulica 17, 2000 Maribor,
SLOVENIA
evgen.torhac@nafta-geoterm.si, jurij.krope@uni-mb.si, darko.goricanec@uni-mb.si

Abstract: The article gives the procedure of determining productivity in separate layers in a geothermal well based on well log temperature. For this purpose a theoretical mathematical model was developed with results examined in a suitable well by using a flow measurement device.

Key-Words: geothermal energy, heat transmission, productivity of a layer, well log temperature, mathematical model, geothermal well

1 Introduction

Geothermal energy in the inner of the Earth is heat that has only been used by mankind in smaller amounts. Until now the use of this kind of energy has been limited to the areas where the geological structure enables the holder of heat (water in liquid state or steam) to carry it from the deeper, hotter layers to the surface, especially on geothermal or volcanic areas [1].

The conventional use of geothermal energy is usually divided into:

- high enthalpy resources (water with temperature above 150°C), used for electricity generation,
- low enthalpy resources (water with temperature under 150°C), usually used directly for heating.

According to data [2] the installed geothermal electricity generating capacities world-wide are increasing every year: In 1995 they were 6.833 MW_e, in 2000 7.974 MW_e and in 2005 8.912 MW_e [3].

The installed capacities of geothermal energy users from low enthalpy resources [4] amounted to 15.145 MW_t in year 2000 at the use of geothermal energy of 190.699 TJ/year. The total installed capacity, reported at the end of 2004 is 27.825 MW_t, almost a two-fold increase over the 2000 data, growing at a compound rate of 12,9 % annually [5].

2 Geothermal energy in Slovenia

Geologic and tectonic structure of Slovenia is complicated, its territory is comprised of five different geological structural units: the Pannonian Basin, Eastern Alps, Southern Alps, border region between Eastern and Southern Alps and Outer Dinarids. Due to the fact that Slovenia lies in an area where Alps, Dinarids and the Pannonian Basin join, folding and thrusting which accompanied the collision of African and European plate created deep ruptures (tectonic zones), which enabled a deeper circulation of water [6].

The depth of Earth's crust is essential for the transmission of water towards the surface. It is the thickest in the western part of Slovenia, around 50 km. The layer gets thinner towards the east, so that in the easternmost part it is only around 30 km.

Water suitable for heat gathering is situated in fissure aquifiers (mostly carbonate, in dolomite and limestone, partially also in sandstone) as well as in granular aquifiers (sand and gravel). Fissure aquifiers are represented by older layers, mostly Mesozoic in age. In tertiary depressions where a full consolidation of sediments has not occurred yet and where the intergranular bonding has not been extracted yet, sand and gravel can be found in depths beyond 1.000 meters.

Slovenia already has 27 locations [7] at its disposal where geothermal water comes from wells, with total installed heat 42 MW_t (of which 53% are used). 750 TJ of heat comes from this source every year. It is being estimated that Slovenia has on its disposal 50.000 PJ of theoretical sources of heat found only in geothermal aquifiers, of which 12.000 PJ are usable.

Search for sources of thermal water in tertiary sediments of the Pannonian basin shows that any significant amounts of thermal water can only be found in Pliocene layers of Mura formation and that the thermal aquifier (which in the whole represents a low enthalpy geothermal system), that is nowhere thicker than 100 meters, supplies water for almost all balneologic- recreational centres in the area of north eastern Slovenia.

There is only one high enthalpy geothermal system known to lie in the area of Slovenia, layers of tertiary basis, which is in smaller depths in its northern part (up to 2000 meters), where the temperature of geothermal water comes up to 100°C. In the southern part, among towns Ptuj, Ormož, Ljutomer and Lendava, these layers can be found in greater depths (4000 to 5000 meters), where geothermal water probably reaches more that 200°C.

3 Well Dobrovnik Do-3g

Well Do-3g lies in the north-eastern part of Slovenia, in municipality Dobrovnik with Gauss Kruger coordinates X= 5 166 870, Y= 5 603 580, Z= 169,3. The well represents a low enthalpy geothermal resource with more watering intervals in depths from 1000 to 1575 meters. It was finished in the period between 30.11.2004 and 20.1.2005. The well Do-3g has been drilled as a research geothermal well to the depth of 1.583,28 meters. The following well log measurements were performed prior to drilling: Dual Laterolog and Gamma Ray (DLL/GR) (968,5 to 1.580 meters). Technical state of the well is shown in picture 1.

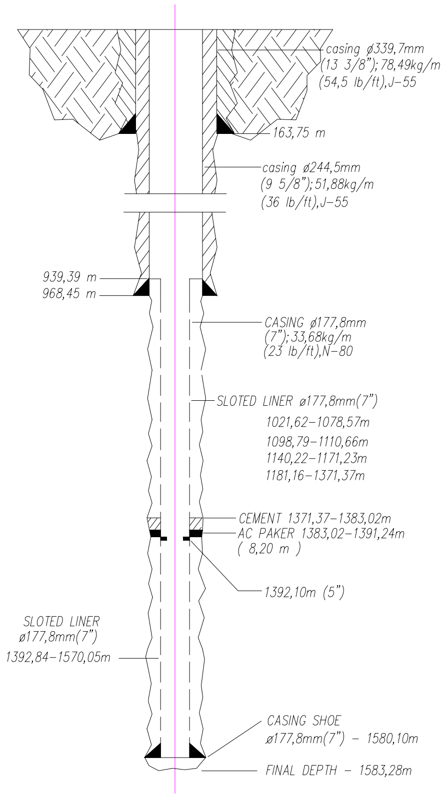
The well produces geothermal water in a self discharging manner in the amount 15 litres/second at the temperature of approximately 60˚C at the wellhead. Balneochemical structure of the water is Na-HCO$_3$ type, with 679 mg/liter of total dissolved solids (TDS). There are no gases in the water.

The structure of geothermal water from well Do-3g is the following:

Na^+ 174 mg/l or 92,56 meq/l
HCO_3^- 482 mg/l or 97,39 meq/l
pH= 8,3
M alkalinity 7,9 mmol/l
Total hardness 8 CaOmg/l
Spec. el. conduct. 670 µS/cm

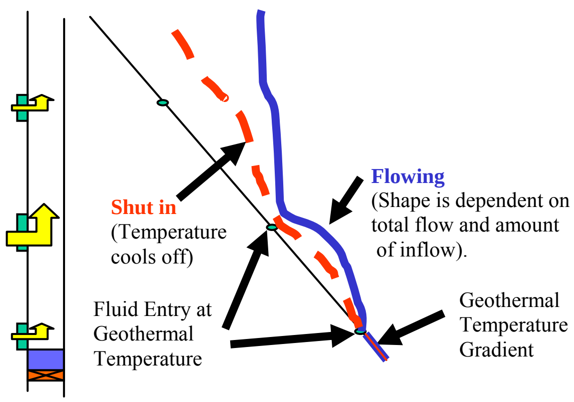
4 Well log temperature Do-3g

Even though measuring the temperature in a well is simple and precise, it is often neglected in practice as a suitable tool for qualitative and quantitative determination of production of separate intervals in a geothermal well.



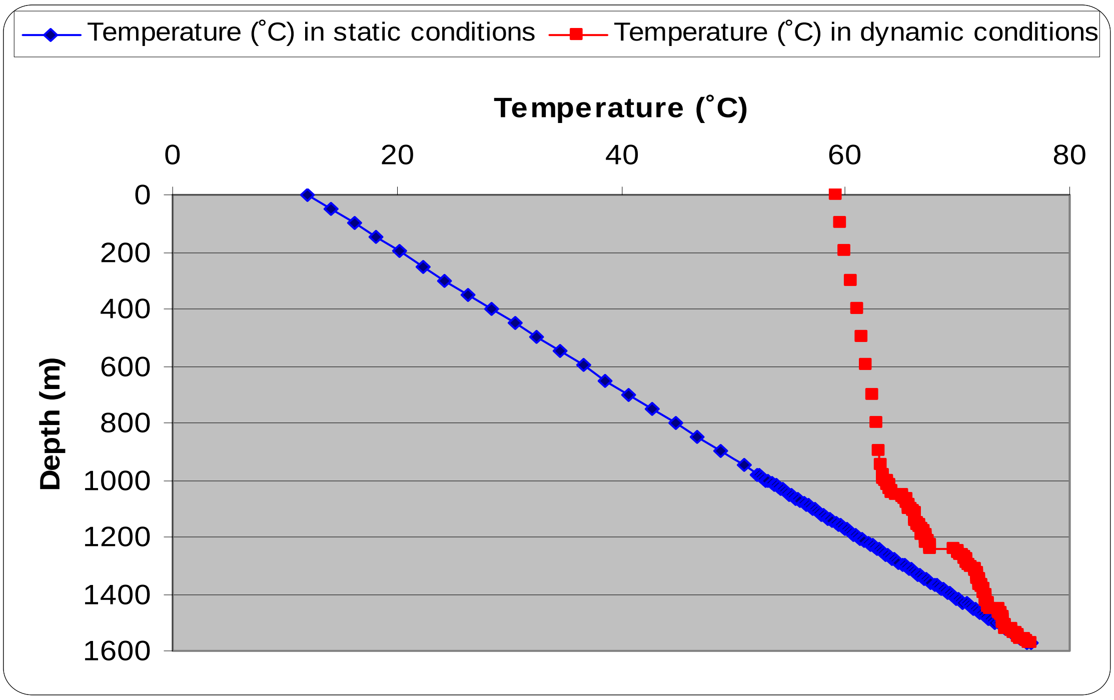
Picture 1: Technical state of well Do-3g

For the interpretation of well log temperature it is necessary to know all the factors that affect the temperature in a well [8]. The factors include the temperature of separate layers, heat transmission between the well and separate layers, convection of heat due to flow of fluids and thermal changes of fluids in dynamic conditions [9] – picture 2.



Picture 2: Temperature profile in a geothermal well

Geothermal temperature gradient (ΔT/Δz) in static conditions (no flow of fluid in the well) and in dynamic conditions (flow of fluid q_v=15 litres/second) needs to be determined in order to make a qualitative and quantitative interpretation of the flow of fluids from separate layers –picture 3.



Picture 3:The temperature gradient in well Do-3g in static and dynamic conditions (q_v=15 l/s)

5 Qualitative and quantitative interpretation of water inflows into the well

After measurements [10] of the temperature gradient in well Do-3g by a temperature probe at static and dynamic conditions the following productive intervals were determined:

-1025 m to 1030 m,
-1045 m to 1055 m,
-1060 m to 1070 m,
-1100 m to 1110 m,
-1145 m to 1150 m,
-1155 m to 1160 m,
-1165 m to 1170 m,
-1190 m to 1195 m,
-1210 m to 1215 m,
-1220 m to 1225 m,
-1235 m to 1250 m,
-1260 m to 1265 m,
-1275 m to 1280 m,
-1300 m to 1310 m,
-1365 m to 1370 m,
-1400 m to 1405 m,
-1440 m to 1455 m,
-1465 m to 1470 m,
-1505 m to 1510 m,
- 1515 m do 1525 m, which show productivity of layers on picture 4.

6 Mathematic model

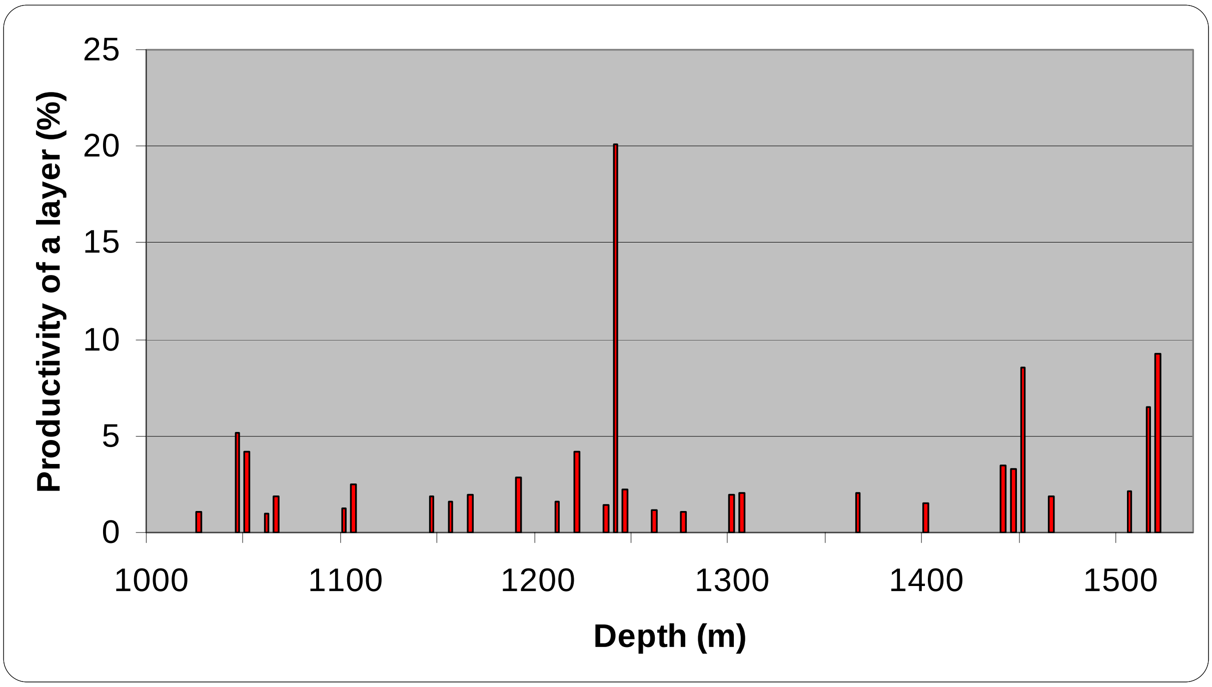
Hydrodynamic and thermodynamic processes going on during the pumping process in the well and surrounding stone are quite complex for an exact integration of a system of differential equations that describe the process [11]. Therefore the analytical model is based on a simplified presumption which considers the stationary flow without environmental disturbances and temperature loss, so we can define volume flows of separate layers based on the measured temperatures of layers at static and dynamic conditions on various depths.

When recording the analytical model of the system in well – picture 1 – we use the heat balance equation (1):

$$\Phi = \sum_{i=1}^{N} c_{pi} \cdot q_{mi} \cdot t_i = \sum_{i=1}^{N} c_{pi} \cdot q_{vi} \cdot \rho_i \cdot t_i \qquad (1)$$

where: C_{pi} - specific heat (J/kgK)
q_{vi} - volume flow (m^3/s)
t_i - temperature (˚C)
ρ_i - density (kg/m^3)
Φ - heat flow (J/s=W)

Due to small changes in temperature of geothermal water along the well, density and specific heat are assumed to be constant.



Picture 4: Productivity of separate layers (%) at dynamic conditions (q_v=15 l/s)

7 Conclusion

Productivity of separate layers in a geothermal well can be qualitatively and quantitatively defined on the basis of well log temperature (measurement of temperature depending on the depth) in static and dynamic conditions.

Where fluid comes into the well, anomalies can be observed, which serve for a qualitative determination of productive layers. The qualitative determination of layer productivity we carried out based on well log temperature is in total agreement with the interpretation of well log measurements DLL and GR.

The anomalies which occur due to the inflow of fluids into the well can be used for a quantitative estimation of productivity of separate layers. The developed mathematical model is based on temperature measurements at static and dynamic conditions on various depths and on heat balance of each separate layer.

Productivity of layers in well Do-3g defined on the basis of a mathematical model has been verified by a flow measurement device. The results of the measurements show agreement.

The advantage of temperature measurement in static and dynamic conditions and the mathematical model calculation is in the fact that the productivity of separate layers in a geothermal well can be established quickly and with low costs.

Continuous measurements of productivity and pressures of separate layers in a geothermal well are of vital importance for the analysis of the state of water under ground. In this way it can be determined which layers will be productive in long term, which again helps at defining the location and construction of reinjection well through which the water is returned under ground. Efficient long term use of geothermal water as a renewable resource can only be assured by returning water.

References:

[1] Dickson M.H., Fanelli M., *Geothermal energy-Utilisation and technology*, United Nations Educational Scientific and Cultural Organisation (UNESCO), 2003

[2] Huttrer G.W., The status of world geothermal power generation 1995-2000, *Geothermics,* Vol. 30, 2001, pp. 7-27.

[3] Bertani R., World Geothermal Generation 2001-2005: State of the Art, *Proceedings* World Geothermal Congress, Antalya, Turkey, 2005

[4] Lund J.W., Freeston, D.H., World-wide direct uses of geothermal energy 2000. *Geothermics*, Vol. 30, 2001, pp. 29-68.

[5] Lund J.W., Freeston, D.H., Boyd T.L. World-wide Direct Uses of Geothermal Energy 2005, *Proceedings* World Geothermal Congress, Antalya, Turkey, 2005

[6] Ravnik D., Overview of the geothermal field of Slovenia in the Area between the Alps, the Dinarides and the Pannonian basin, *Tectonophysics,* Vol. 250, 1995, pp. 135-149

[7] Rajver D., Lapanje A. The Current Status of Geothermal Energy Use and Development in

Slovenia, *Proceedings* World Geothermal Congress, Antalya, Turkey, 2005

[8] Nicholson K., *Geothermal fluids*, Springer Verlag Berlin, 1993.

[9] Repsold H. *Well logging in groundwater development*, DVGW, Hannover, Heise, 1989.

[10] Prensky S., Temperature measurement in boreholes: An overview of engineering and scientific applications, *The Log Analyst,* Vol. 33(3), 1992, pp. 313-333

[11] Garbai L., Fényes T., Systems theory study of heat fluxes in case of non-identically zero initial condition, *Hungarian Journal of Industrial Chemistry*, Vol. 27, 1999, pp 161-164.